



Canadian Space Agency

Agence spatiale canadienne



UNIVERSITY OF CALGARY



# A Decade with Swarm-Echo: Past Discoveries, Present Status, and Future Directions

# SWARM

# 10

YEAR ANNIVERSARY

SCIENCE CONFERENCE

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## Swarm 10 Year Anniversary & Science Conference 2024

# CASSIOPE becomes Swarm-E



**CASSIOPE**



**swarm**

*CASSIOPE/e-POP joined Swarm as Swarm-E in 2018*

	Swarm-A/C	Swarm-B	Swarm-E
Launch	Nov 2013	Nov 2013	<b>Sep 2013</b>
Inclination (deg)	87.4	87.8	<b>81.0</b>
Altitude (km)	475	513	<b>325-1055</b>
Operations	Continuous	Continuous	<b>Bursty</b>

# Swarm-E Science Payload (e-POP)



Beacon Transmitter

150/400/1066 MHz

CERTO

Auroral Imager

650–1000 nm; 630 nm

FAI

GPS Receivers

5 units, L1 and L2

GAP

Ion Mass Spectrometer

0.5-70 eV/q; 1-40 amu/q

IRM

Magnetometer

Dual mags, 160 samples/s

MGF

Radio Receiver

0.01-18 MHz; 31.25 kHz bandwidth

RRI

Electron Imager

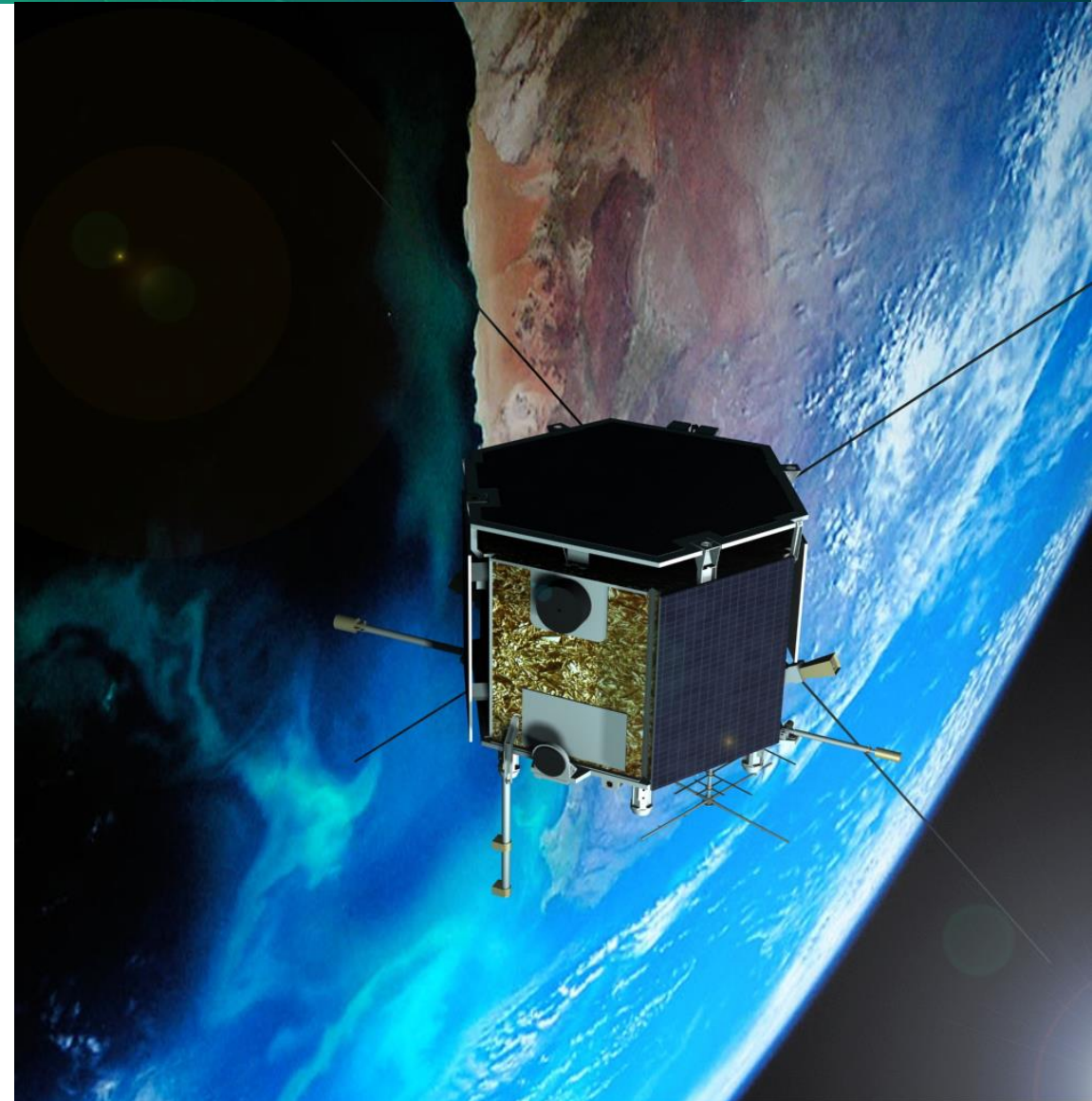
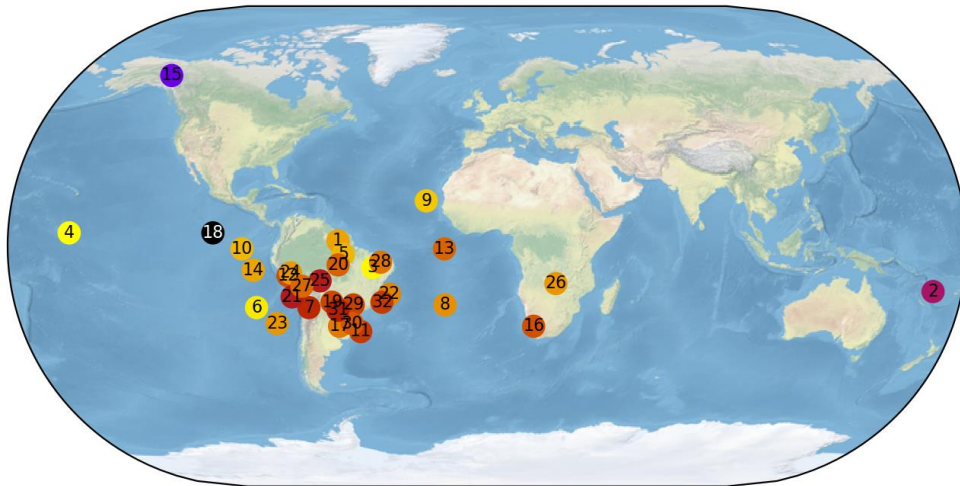
0.1-350 eV ions or electrons

SEI

# Highlights from the last 10 years

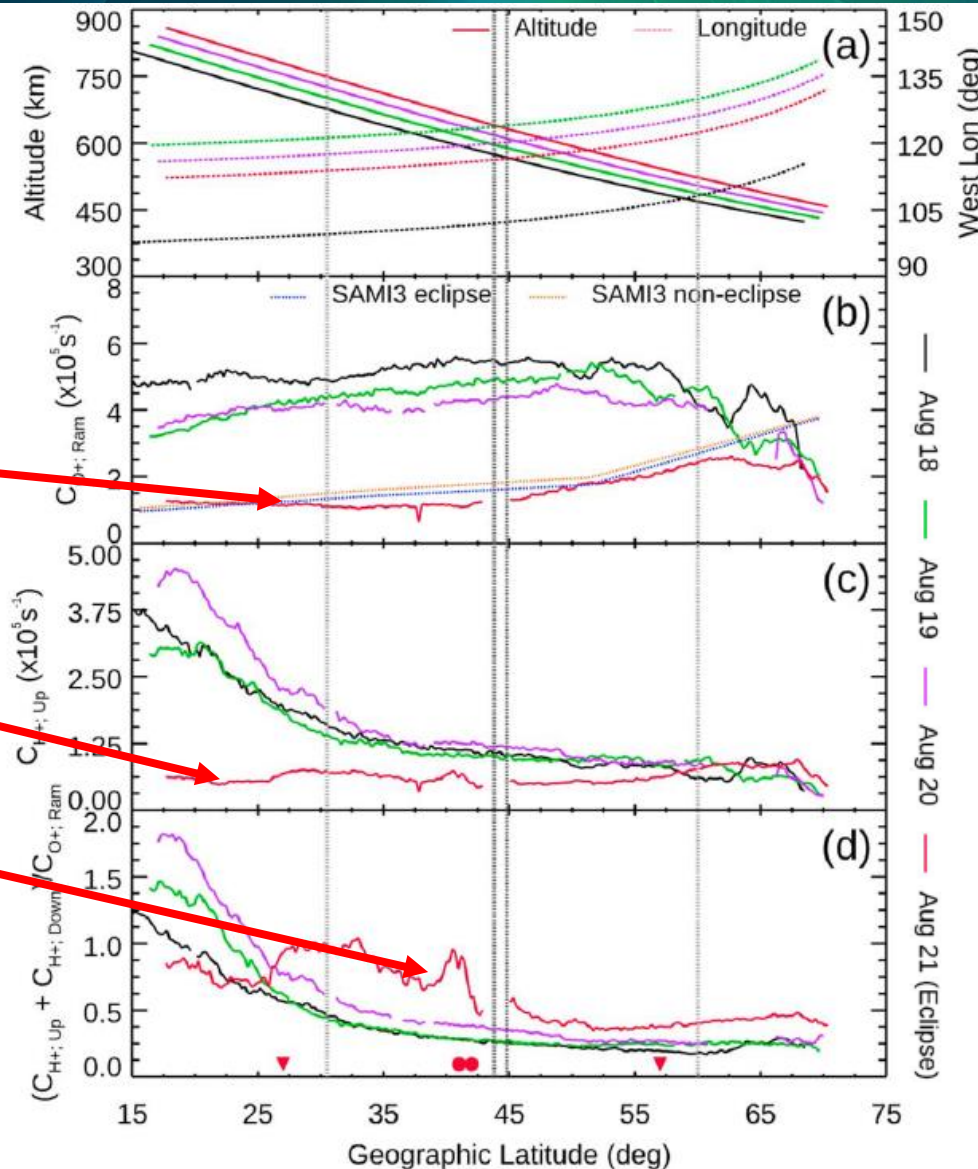


- 12 TB of raw and processed data products
- 3000+ close encounters (<400 km) with Swarm-A/B/C
- 400+ passes operating in conjunction with SuperDARN radars
- 118 high-resolution data sets for extremely close (< 5 km) encounters with resident space objects
- 32 spacecraft bus CPU resets caused by single event upsets (high-energy particle strikes)





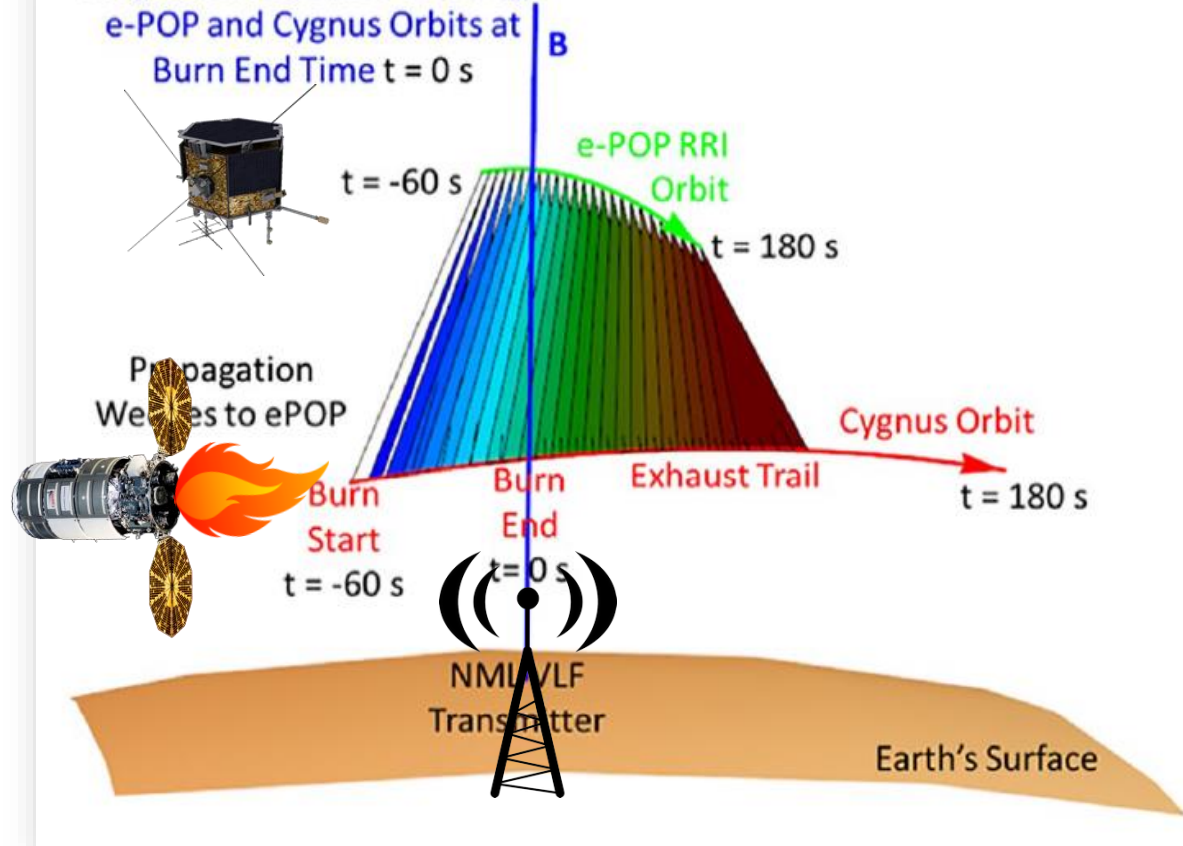
- Ion mass spectrometer measurements from the 2017 total solar eclipse and the days preceding
- 40% decrease in topside plasma density
- Disruption of upward H<sup>+</sup> flow
- Changes in the H<sup>+</sup>/O<sup>+</sup> composition



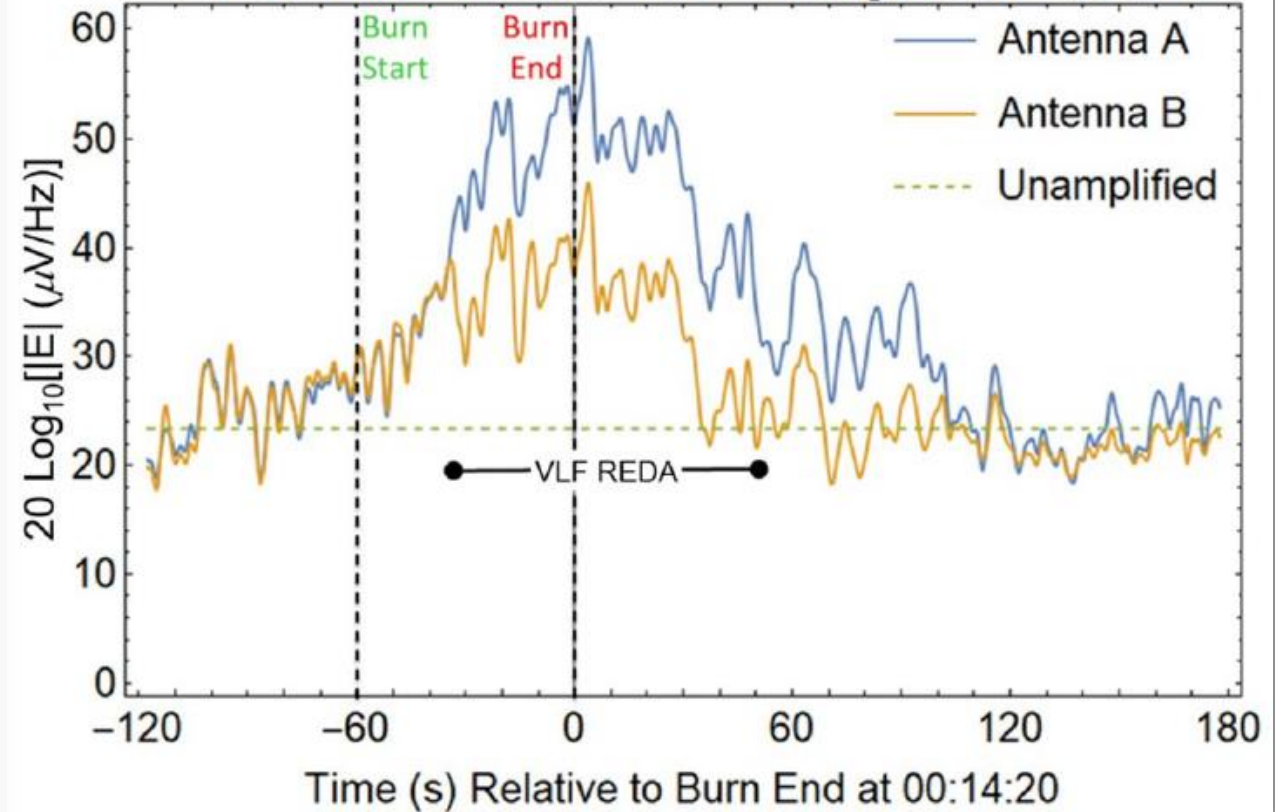
Red line = Eclipse Day

Yau, A. W., Foss, V., Howarth, A. D., Perry, G. W., Watson, C., & Huba, J. (2018). Eclipse-induced changes to topside ion composition and field-aligned ion flows in the August 2017 solar eclipse: e-POP observations. *Geophysical Research Letters*, 45. <https://doi.org/10.1029/2018GL079269>

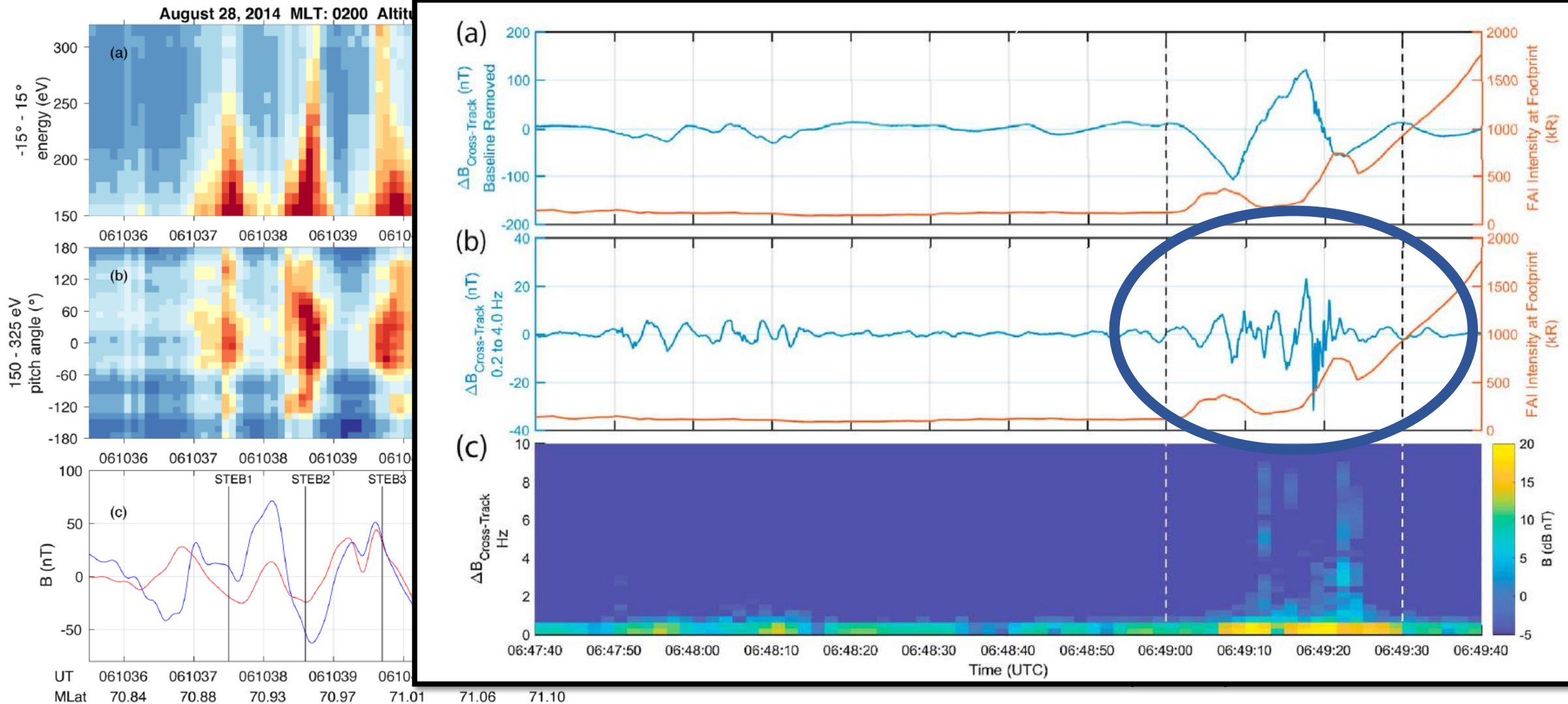
Magnetic Field Lines Through e-POP and Cygnus Orbits at Burn End Time  $t = 0$  s



e-POP RRI 25.2 kHz Line Strength, 2020/05/26



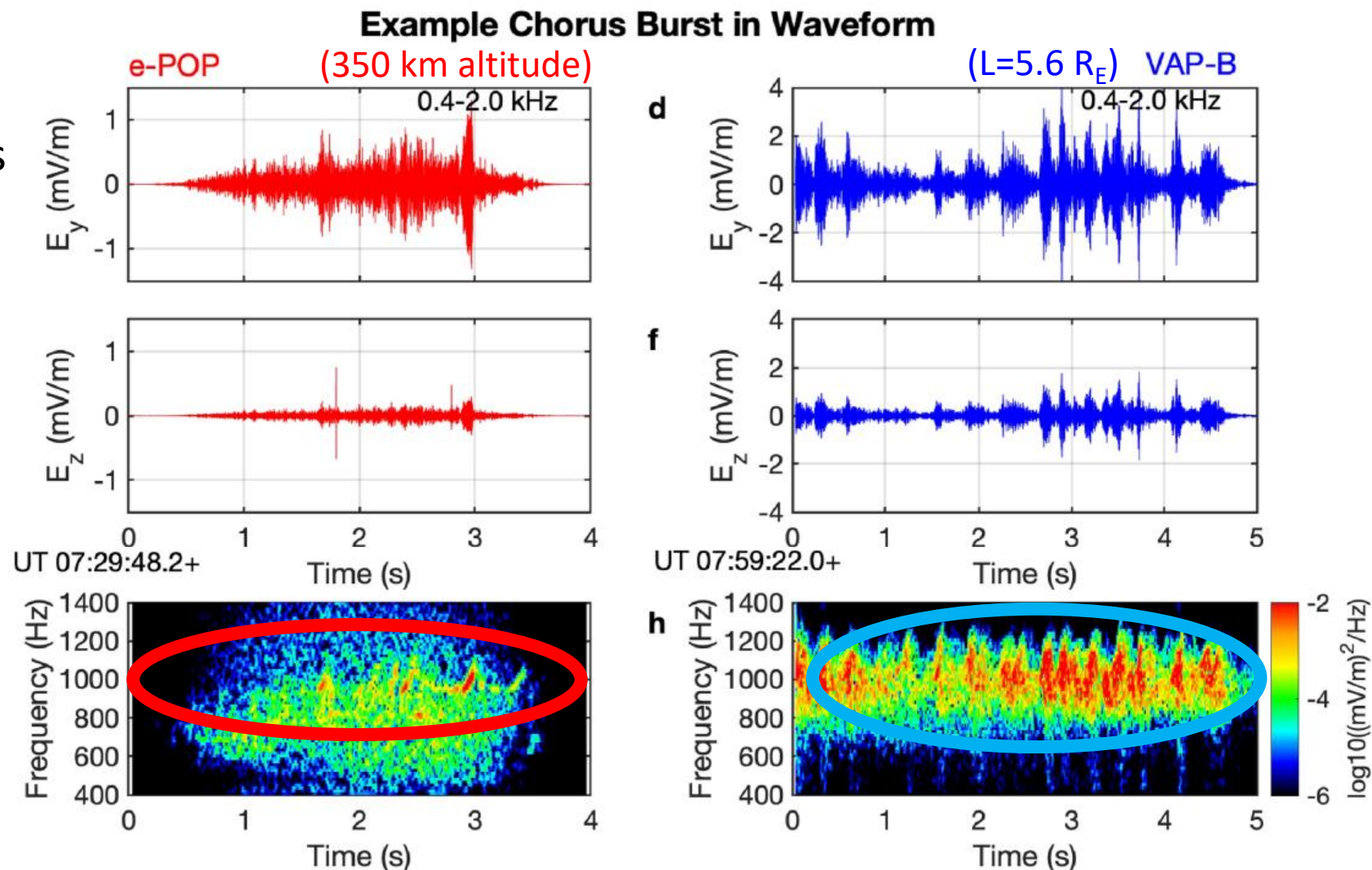
Bernhardt, P. A., Bougas, W. C., Griffin, M. K., Watson, C., Langley, R. B., Howarth, A. D., et al. (2021). Strong amplification of ELF/VLF signals in space using neutral gas injections from a satellite rocket engine. *Radio Science*, 56, e2020RS007207. <https://doi.org/10.1029/2020RS007207>



Wu, J., Knudsen, D. J., Shen, Y., & Gillies, D. M. (2021). e-POP observations of Suprathermal electron bursts in the ionospheric Alfvén resonator. *Journal of Geophysical Research: Space Physics*, 126, e2020JA028005. <https://doi.org/10.1029/2020JA028005>

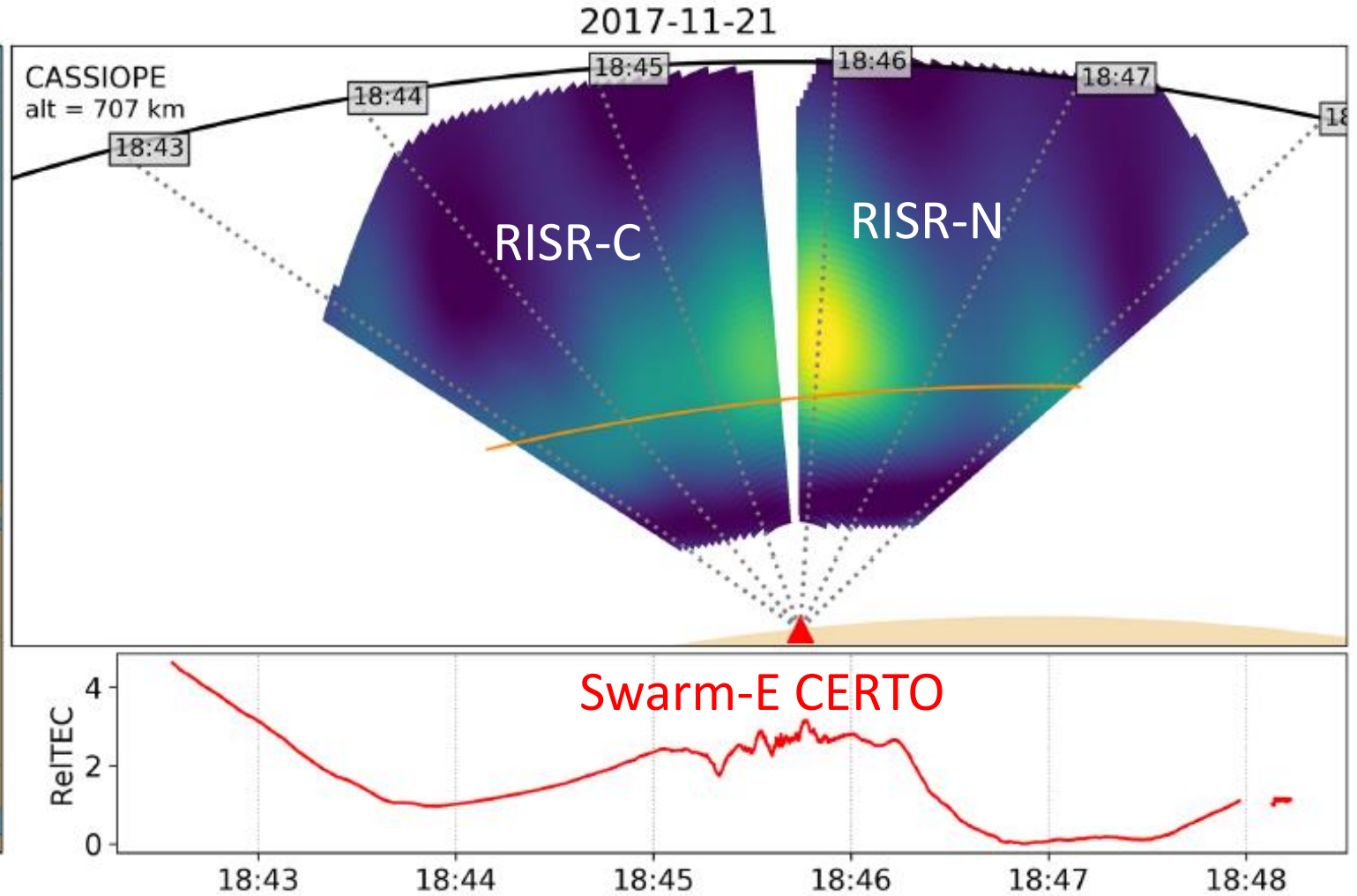
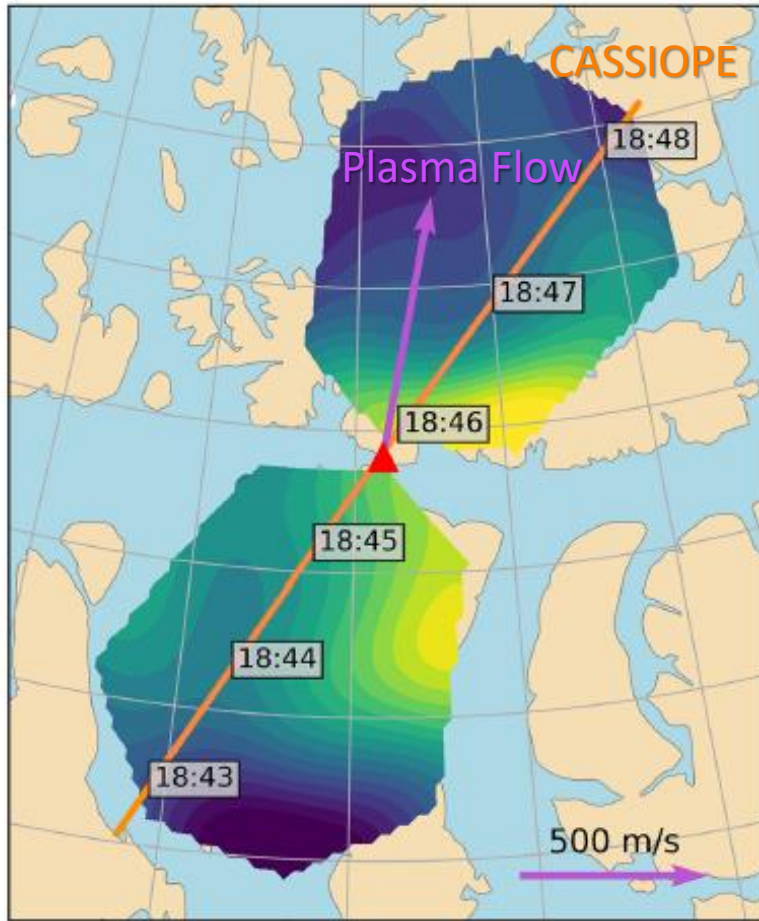
Miles, D. M., Mann, I. R., Pakhotin, I. P., Burchill, J. K., Howarth, A. D., Knudsen, D. J., ... Yau, A. W. (2018). Alfvénic dynamics and fine structuring of discrete auroral arcs: Swarm and e-POP observations. *Geophysical Research Letters*, 45. <https://doi.org/10.1002/2017GL076051>

- First direct evidence of chorus wave propagation from the magnetosphere to the ionosphere to the ground
- Waves guided by density crests
- Important for relativistic electron precipitation from the radiation belts



Shen, Y., Chen, L., Zhang, X.-J., Artemyev, A., Angelopoulos, V., Cully, C. M., et al. (2021). Conjugate observation of magnetospheric chorus propagating to the ionosphere by ducting. *Geophysical Research Letters*, 48, e2021GL095933. <https://doi.org/10.1029/2021GL095933>





# Swarm-E/e-POP Data Tools



- ✓ e-POP Data Handbook
- ✓ e-POP Data Download
- ✓ e-POP Data Explorer (eDEX)
- ✓ e-POP Payload Quicklook
- ✓ e-POP Ephemeris Library
- ✓ e-POP Data Tutorials

### e-POP Data

**Available Data Products**

Below is a list of the available published data products for the e-POP data set.

CASSIOPE/Swarm-E Spacecraft Products

- Ephemeris Data
- Orbit Data
- Quaternion Data
- Housekeeping Telemetry Data

e-POP Payload Products

- Data Availability
- Payload Quicklook

Auroral Imager (FAI)

- Summary Plot
- Quicklook Movie
- HDF5 Files of Images
- PNG Files of Images

Magnetic Field Instrument (MGF)

- Summary Plot
- Quicklook Plot
- CHAOS Residuals Plot
- CDF File – Magnetic Data @ 1Hz
- CDF File – Magnetic Data @ 160Hz

GPS Instrument (GAP)

- Quicklook Plot
- Raw GPS Messages
- Observation RINEX

### e-POP Data Handbook

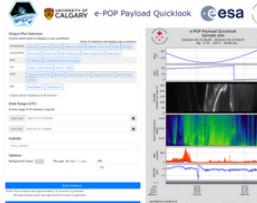


A document describing the available processed e-POP data products. Each processed data product has a high-level description of the file, and the detailed information required when working with the data.

### e-POP Data Explorer: eDEX

The most powerful and efficient way to find and download e-POP data in most cases, eDEX is a complex comprehensive constraint-based filtering webapp tool, which filters on geophysical, spacecraft, and payload constraints. An API is also available for automated requests.

### e-POP Payload Quicklook

A tool to generate custom e-POP quicklook stackplots. It provides a custom output product based on requested quicklook plots and time range. Useful for comparing plots from different instruments on the same timescale.

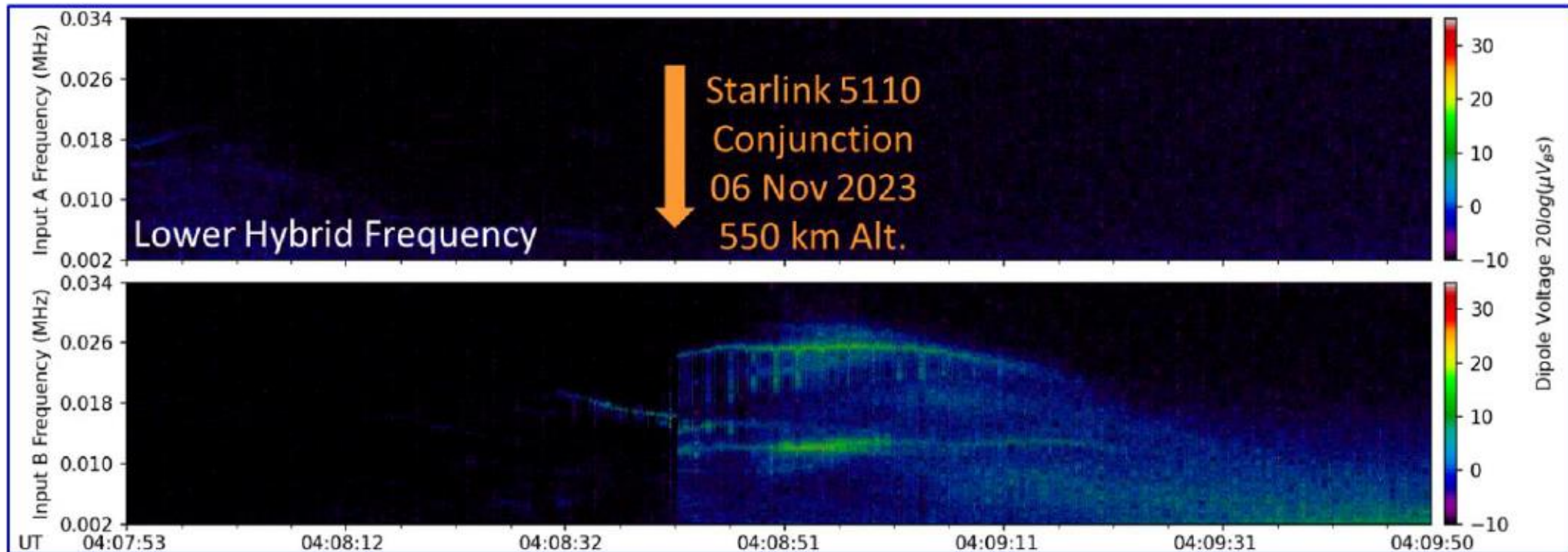


<https://epop.phys.ucalgary.ca/data>

# Present Status



- Swarm-E is still active but not in 'Routine' operations
- Attitude is sub-optimal: solar pointing with 6-minute spin
- Data collection
  - GPS data nearly continuous
  - Close encounters with resident space objects
  - Coordinated experiments with HAARP
  - Other events (e.g. solar eclipse)



# Thank You!



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Agency

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